UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
10/813,168	03/31/2004	Michael M. Albert	1857.2390000/MVM/CMB	4453

26111 7590 04/28/2006

STERNE, KESSLER, GOLDSTEIN & FOX PLLC
1100 NEW YORK AVENUE, N.W.
WASHINGTON, DC 20005

EXAMINER	
CONSILVIO, MARK J	
ART UNIT	**PAPER NUMBER**
2872	

DATE MAILED: 04/28/2006

Please find below and/or attached an Office communication concerning this application or proceeding.

UNITED STATES DEPARTMENT OF COMMERCE
U.S. Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450

10-813,168 H'A

APPLICATION NO./ CONTROL NO.	FILING DATE	FIRST NAMED INVENTOR / PATENT IN REEXAMINATION	ATTORNEY DOCKET NO.

EXAMINER

ART UNIT	PAPER
	20060424

DATE MAILED:

Please find below and/or attached an Office communication concerning this application or proceeding.

Commissioner for Patents

Attached is a courtesy copy of a translation of reference RU 2166819 C2 that was originally supplied by applicant in an IDS filed 12/19/2005 and discussed in an after-final interview granted on 4/4/2006.

MARK CONSILVIO
PATENT EXAMINER
(571) 272-2453

DREW A. DUNN
SUPERVISORY PATENT EXAMINER

PTO 06-3852

CY=EP DATE=20010510 KIND=C2
PN=2,166,819

LASER RESONATOR OPTICAL ELEMENT
[OPTICHESKIY ELEMENT LAZERNOGO REZONATORA]

Niz'yev V. G.

UNITED STATES PATENT AND TRADEMARK OFFICE
Washington, D.C. APRIL 2006

Translated by: FLS, Inc.

PUBLICATION COUNTRY	(19):	RU
DOCUMENT NUMBER	(11):	2,166,819
DOCUMENT KIND	(12):	C2
PUBLICATION DATE	(43):	20010510
PUBLICATION DATE	(45):	
APPLICATION NUMBER	(21):	10,813,168
APPLICATION DATE	(22):	19990809
ADDITION TO	(61):	
INTERNATIONAL CLASSIFICATION	(51):	H 01 S 3/08
DOMESTIC CLASSIFICATION	(52):	
PRIORITY COUNTRY	(33):	
PRIORITY NUMBER	(31):	
PRIORITY DATE	(32):	
PRIORITY COUNTRY	(33):	
PRIORITY NUMBER	(31):	
PRIORITY DATE	(32):	
PRIORITY DATE	(32):	
DESIGNATED CONTRACTING STATES	(84):	
INVENTORS	(72):	V. G. Niz'yev
APPLICANT	(71):	V. G. Niz'yev
TITLE	(54):	Laser resonator optical element
FOREIGN TITLE	(54A):	Opticheskiy element lazernogo rezonatora

(54) LASER RESONATOR OPTICAL ELEMENT

(57) Abstract

The invention pertains to laser technology, more specifically laser resonators. The device is a reflecting diffraction element, which contains a substrate and periodic metal relief applied to its working surface with period less than half the radiation wavelength. The direction of relief lines forms with the desired direction of the electric field vector an angle less than 15°. The width d and height h of the relief projections are determined by the formulas:

$$d \approx T \cdot \frac{(n-1)}{n};$$

$$h \approx \frac{\lambda}{4 \cdot \sqrt{n}},$$

where T is the relief period; n is the substrate index of refraction; lambda is the radiation wavelength. The technical achievement of the invention: creation of a laser resonator optical element with high selectivity to radiation with azimuthal or radial polarization and assurance of high reflecting capability and element radiating stability.

The invention pertains to laser optics, more specifically to laser resonators. /1*

An optical element is known as part of a laser resonator [1]. It has a well polished surface, high reflection factor, and is used as an opaque or rotating mirror.

A shortcoming of this element is the fact that it has radiation polarization selectivity, that is the radiation reflection factor of any polarization from its surface is identical. Laser radiation, which exits from a resonator that contains only elements that do not have polarization selectivity, has random, uncontrolled polarization. At the same time it is known that radiation polarization greatly

* Number in the margin indicates pagination in the foreign text.

affects laser treatment parameters of metals [2]. When using radiation with random polarization for laser treatment of metals (cutting, welding, punching holes) the radiation absorption factor on the walls of a channel K equals the average arithmetic value of the absorption factors of P-and S-waves, $K=(K_{IP} + Ks)/2$ (P- and S-waves differ in their electric field vector orientation with respect to the radiation incidence plane on the surface [3]. For large angles of incidence the absorption factors for P- and S-waves differ strongly, so that $K \approx 0.5Kr$. The potential possibilities of laser radiation absorption, embedded in the P-wave absorption mechanism, are not produced. Another serious disadvantage is the fact that random, uncontrolled polarization situation leads to great instability of parameters and treatment quality.

During radiation transmission in a metal circular waveguide radiation absorption that corresponds to $K=(Kr + Ks)/2$, is also not optimal. It is significantly higher than the possible minimal value related to the S-wave absorption.

An optical element of a laser resonator [4] is known that is made in the form of a linear metallic diffraction grating. The grating slits are applied along straight lines parallel to one another.

Such an element has radiation polarization selectivity, that is, the radiation reflection factor for polarization with electric field vector direction along the grating slits differs from the radiation

reflection factor for polarization with electric field vector direction across the grating slits. Any transverse resonator mode can have linear polarization in any direction, so that even a very small polarization selectivity is sufficient so that the laser radiation, which comes from a resonator that contains such an element, has stable, controlled linear polarization, with an electric field vector directed along the grating slits.

The main disadvantage of this element is the fact that during its installation in the resonator the laser radiation polarization is linear, with identical electric field vector direction at all points of the laser beam cross section. When using such radiation for cutting and welding metals only a small portion of radiation is absorbed and is spent on destruction of the material. This deficiency occurs for any mutual orientation of the beam movement velocity vector and E vector oscillation plane.

In the case when the beam movement velocity vector is perpendicular to the vector oscillation plane E, the radiation absorption factor on the leading edge of the cut is small (corresponds to S-wave absorption).

In the case when the beam movement velocity vector is parallel to the vector oscillation plane E, the radiation absorption factor on the leading edge of the cut is great (corresponds to P-wave absorption), however absorption on the side walls of the channel is

small (corresponds to S-wave absorption), their disintegration is ineffective, which prevents beam penetration into the material.

Moreover, if there is an arbitrary beam movement direction with respect to the vector oscillation plane E the cut parameters (depth, width, shape) depend on the beam movement direction, which is unacceptable for many applications.

During the transmission of such radiation on a metallic circular waveguide radiation absorption is not uniform on the waveguide walls, which leads to great losses and beam shape deformation.

An optical element is known that was installed in a laser resonator to create laser radiation with radial direction of polarization [5] (prototype). It is made in the form of a tapered shape Brewster window. A laser beam with radial polarization direction is formed at the exit of a resonator with such an element.

Such an element has a number of disadvantages. One of them is the use of a through optical element, the Brewster window, complex shape, in the form of a cone. In more widely used production technology carbon dioxide lasers to make through optical elements crystalline materials are used: zinc selenide, sodium chloride. The manufacture of the cone requires intermediate pieces of large size and complex manufacturing equipment. The through optical elements have lower beam stability than reflective ones, and their installation within the resonator limits the maximum power of the laser. Radiation, reflected from the internal surface of the cone

during beam incidence on the side of the cone base, is focused inside the cone, which can lead to its beam damage with laser high power. Selectivity of such an element is determined by the radiation reflection factor from the cone surface and is low, in many cases insufficient. Insofar as only certain modes (TEMno1) [6] of the set of transverse modes can have radial polarization direction, we speak not simply of binding the radial polarization direction, but of selection of those transverse modes that such polarization can have.

The aim of the invention is creation of a laser resonator optical element, which has high selectivity to radiation with radial or azimuthal polarization direction, and which has high reflection factor and beam stability. /2

This goal is achieved by the fact that the laser resonator optical element for selection of modes with radial or azimuthal polarization direction is made in the form of a reflecting diffraction element, which contains a substrate and periodic metallic relief with period less than the radiation wavelength deposited on its working surface. The direction of the relief slits forms with the electric field vector direction an angle less than 15°. The width d and height h of the relief projections are determined by the formulas:

$$d \approx T \cdot \frac{(n-1)}{n};$$

$$h \approx \frac{\lambda}{4 \cdot \sqrt{n}},$$

where T is the relief period; n is the substrate refractive index; lambda is the radiation wavelength.

To select modes with radial polarization direction the relief figure is formed from straight segments, at any point of the working surface of the generatrices with the line drawn from the resonator axis to this point, an angle less than 15°. In particular the relief drawing is formed by segments of straight lines that intersect on the resonator axis. To ensure constancy of the relief period it is suggested that the surface of the optical element be divided into sectors with vertices on the resonator axis, in each sector the relief drawing is formed by segments of straight lines parallel to the bisector of the sector angle.

To select modes with azimuthal polarization direction the relief figure is formed so that at any point of the effective surface the direction of the slits forms with the line drawn from the resonator axis to this point an angle in the limits of 90+/-15°. In particular, the relief figure is formed by concentric circles with center on the resonator axis.

The principle of the invention is illustrated by Figs. 1-4. The laser resonator optical element is made in the form of a reflecting diffraction element, which is polarization selective. A periodic metallic relief is deposited on the substrate (see Fig. 1) with refractive index n. The relief period T is less than the radiation

wavelength lambda. The width of relief projections d and their height h are determined from the formulas:

$$d \approx T \cdot \frac{(n-1)}{n};$$

$$h \approx \frac{\lambda}{4 \cdot \sqrt{n}},$$

The relief figure is formed of straight segments, which at any point of the effective surface form with the line drawn from the resonator axis to this point, an angle less than 15°. To select modes with radial polarization direction the relief figure is formed of straight segments, which at any point of the effective surface form with the line drawn from the resonator axis to this point, an angle less than 15°. In particular, the relief figure is formed by segments of straight lines, which intersect on the resonator axis (Fig. 2). To ensure constancy of the relief period on the entire surface of the optical element (see Fig. 3) this surface is divided into sectors with vertices on the resonator axis, in each sector the relief figure is formed by segments of straight lines parallel to the bisector of the sector angle.

To select modes with azimuthal polarization direction the relief figure is formed so that at any point of the effective surface the direction of the slits forms with the line drawn from the resonator axis to this point, an angle in the limits of 90+/-15°. In particular the relief figure is formed by concentric circles with center on the resonator axis (Fig. 4).

Optical elements made in this way have excellent polarization selectivity close to 100%, which ensures effective generation of radiation with radial or azimuthal polarization direction. This design of the optical element ensures high reflecting capability and radiation stability.

The element works in the following way. In the proposed optical element the periodic structure has a period less than the radiation wavelength. In this case, this structure is equivalent to the uniform optical layer, whose thickness equals the relief thickness. However, optical parameters of this layer are different for radiation with electric field vector along the relief lines and for radiation with electric field vector across the relief lines. Equivalent layer parameters (dielectric constant epsilon$_{\parallel}$, epsilon$_{\perp}$ and the refractive index

$n_{\parallel} = \varepsilon_{\parallel}^{1/2}$, $n_{\perp} = \varepsilon_{\perp}^{1/2}$) are determined by the existing ratios for electromagnetic waves on the separation boundary of two media. In our case these are air and metal, which are in the layer. The general formulas for epsilon$_{\parallel}$ and epsilon$_{\perp}$ have the form:

$$\varepsilon_{\parallel} = \varepsilon_B \cdot d_B / T + \varepsilon \cdot d / T;$$
$$1/\varepsilon_{\perp} = (1/\varepsilon_B) \cdot (d_B/T) + (1/\varepsilon) \cdot (d/T);$$
$$d_B = T - d. \quad (1)$$

Here epsilon$_B$, epsilon are the permittivity of air and the deposited material respectively; d_B, d are the width of depressions (air gaps) and projections (metal strips), respectively; T is the

period. For air $\epsilon_B = 1$, for metal $\epsilon > 1$, and the formulas are greatly simplified:

$$\epsilon_{\parallel} = \epsilon \cdot d/T;$$
$$\epsilon^{\perp} = T/(T-d). \quad (2)$$

It is known that epsilon for metal exceeds epsilon for dielectrics by several orders of magnitude, which determines the excellent reflective properties of metal. The value of $\epsilon_{\parallel}$ according to the formula remains great, therefore the metallic nature of radiation reflection with vector E, parallel to the relief lines, is retained. The reflection factor of this polarization is close to 100% and does not depend on layer thickness. /3

For polarization with vector E perpendicular to the relief lines, $\epsilon^{\perp}$ strongly depends on the selected relief parameters. Therefore, to increase the polarization selectivity of an element the optical layer thickness h and the refractive index $n^{\perp} = \epsilon^{\perp\, 1/2}$ are chosen on the condition of an antireflection coating, which ensures minimal reflection factor of this polarization, even reaching 0%. One must observe two conditions for an antireflection coating [7]: for the layer refractive index $n^{\perp}$ and for the optical layer thickness h:

$$n^{\perp} = n^{1/2};$$
$$h = \lambda/(4 \cdot n^{\perp}),$$

here n is the substrate refractive index.

Considering that $n^{2/\perp} = T/(T-d)$, we get the final formulas

$$d = T \cdot \frac{(n-1)}{n};$$

$$h = \frac{\lambda}{4 \cdot \sqrt{n}} \quad (3)$$

Thus, radiation with E vector, parallel to the relief line, is reflected from the proposed optical element with reflection factor close to 100%, typical for a metal surface.

Radiation with E vector, perpendicular to the relief lines is not reflected because for this polarization layer properties are chosen (its index of refraction and thickness), which correspond to antireflection coating. Large losses of radiation for such polarization prevent generation of modes with polarization, at which the vector E, perpendicular to relief lines. To select modes with radial or azimuthal polarization direction the direction of relief slits at any point of its effective surface must coincide with the direction of the electric field vector, or the angle between them must be small, less than 15°. At such angles a certain reduction of element quality is not important.

Numerical example. We obtain the usual materials for making opaque mirrors of production lasers: substrate of silicon n=3.4, relief material is copper, radiation wavelength lambda = 10.6 mcm. We choose the relief period T < lambda, T = 7 mcm and from formulas (3) we find the width of the copper projections d = 4.95 mcm, and the relief depth h = 1.44 mcm. With radiation incidence perpendicular to the surface for an ordinary copper mirror the radiation reflection

factor is 98.8%, and the radiation reflection index from the relief surface, with vector E parallel to the relief lines equals 98.4%. Theoretical radiation reflection factor with vector E perpendicular to the relief lines from such a structure, with observance of antireflection layer conditions equals zero.

During the interaction of radiation with the metal surface the reflection factor depends on the angle of incidence. And for laser treatment of metals of great thickness and with radiation transmission along a metallic circular waveguide the angle of incidence is great, close to the main angle which in turn is close to 90°. We evaluate the positive effect when using the proposed invention, taking for an example the angle of incidence equal to the main angle. Table 1 presents calculation results for laser cutting of steel: K_p and K_s are the absorption factors for P- and S-waves, respectively. Radiation absorption when using a beam with radial polarization direction is two times greater that when using radiation with circular polarization.

Table 2 presents calculation results for radiation transmission along a copper waveguide. Radiation losses on waveguide walls for azimuthal polarization direction are 800 times less than for circular polarization.

When using radiation with radial polarization for laser treatment of metals (cutting, welding, making holes), absorption in all walls occurs according to the same principle, while the

absorption factor has maximally possible value, when it corresponds to P-wave absorption. More intense disintegration of material occurs. The beam penetrates more deeply into the material. Limiting parameters of treatment increase due to improved effectiveness of the use of laser radiation.

The use of the proposed optical element of a laser resonator in a laser for treating metals allows one to increase the cutting parameters (thickness of treated metal or cutting rate) by the factor 1.5-2 in comparison with the prototype.

During transmission of radiation with azimuthal polarization direction along a metal circular waveguide the radiation absorption losses on the walls correspond to physically minimal value associated with S-wave absorption.

Information sources:

1. Production lasers. Manual. Edited by G. A. Abil'siitov. Moscow: Mashinostroyeniye, 1991, Vol 2, p. 272.

2. A. G. Grigor'yants, A.A. Sokolov. "Laser cutting of metals," book 7 of the series Laser equipment and technology. Moscow: Vysshaya shkola, 1988, p. 56-61; V.P. Grashchuk, V.I. Kirsey, V.A. Shinkarev. Effect of carbon dioxide laser radiation polarization on geometric parameters of melting during welding of metals. Kvantovaya elektronika 13, 12, 1986, p. 2515-2518.

3. B.M. Yavorskiy, A.A. Detlaf. Manual of Physics. Moscow, Nauka, 1974, p. 587-589.

4. Physics Encyclopedia. Moscow: Sovetskaya entsiklopediya, 1988, Vol. 1, p. 657-660.

5. Chen-Shing shih, Palos Verdes Estates, Calif. Radial Polarization Laser Resonator, United States patent No. 5,359,622, Oct. 25, 1994.

6. Laser Manual. Edited by A.M. Prokhorov. Moscow. Sov. Radio, 1978, Vol 2, p. 21.

7. Physics Encyclopedia. Moscow. Sovetskaya entsiklopediya, 1988, Vol. 4, p. 149-150. /4

CLAIMS

1. Laser resonator optical element for selection of modes with radial or azimuthal polarization direction characterized in that it is made in the form of a reflecting diffraction element, which contains a substrate and periodic metallic relief deposited on its effective surface with period less than the radiation wavelength, direction of relief slits at any point of its effective surface forms with the electric field vector direction an angle less than 15°, width d and height h of the relief projections are determined from the formulas:

$$d = T\,\frac{(n-1)}{n};$$

$$h = \frac{\lambda}{4\cdot\sqrt{n}},$$

where T is the relief period;

n is the substrate refractive index;

lambda is the radiation wavelength.

2. Device according to Claim 1 characterized by the fact that to select modes with radial polarization direction the relief figure is formed of straight segments, which at any point of the effective surface form with the line drawn from the resonator axis to this point, an angle less than 15°.

3. Device according to Claim 2 characterized in that the optical element surface is formed by segments of straight lines that intersect on the resonator axis.

4. Device according to Claim 2 characterized in that the optical element surface is divided into sectors with vertices on the resonator axis, in each sector the relief figure is formed by segments of straight lines parallel to the bisector of the sector angle.

5. Device according to Claim 1 characterized in that to select modes with azimuthal polarization direction the relief figure is formed so that at any point of the effective surface the direction of the slits forms with the line drawn from the resonator axis to this point an angle in the limits of 90 +/- 15°.

6. Device according to Claim 5 characterized in that the relief figure is formed by concentric circles with center on the resonator axis.

Table 1

Металл, применение	Главный угол	K_P для радиальной поляризации	$K_P + K_S$ для круговой поляризации	K_S для азимутальной поляризации	Выигрыш в поглощении $K_P/(K_P + K_S)$
Лазерная резка стали	85.7°	48.2%	24.5%	0.7%	≈ 2

Key:

Metal, use	Main angle	K_P for radial polarization	$K_P + K_S$ for circular polarization	K_S for azimuthal polarization	Gain in absorption $K_P/(K_P+K_S)$
Laser cutting of steel					

Table 2

Металл, применение	Главный угол	K_P для радиальной поляризации	$K_P + K_S$ для круговой поляризации	K_S для азимутальной поляризации	Выигрыш в поглощении $(K_P + K_S)/K_S$
Передача излучения по медному волноводу	89°	31.3%	15.7%	0.02%	≈ 800

Key:

Metal, use	Main angle	K_P for radial polarization	$K_P + K_S$ for circular polarization	K_S for azimuthal polarization	Gain in absorption $(K_P+K_S)/K_S$
Radiation transmission along copper waveguide					

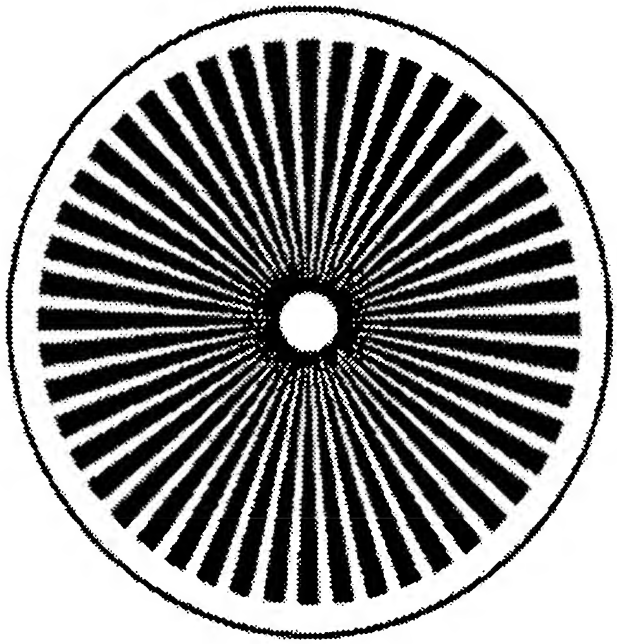

Figure 2

/6

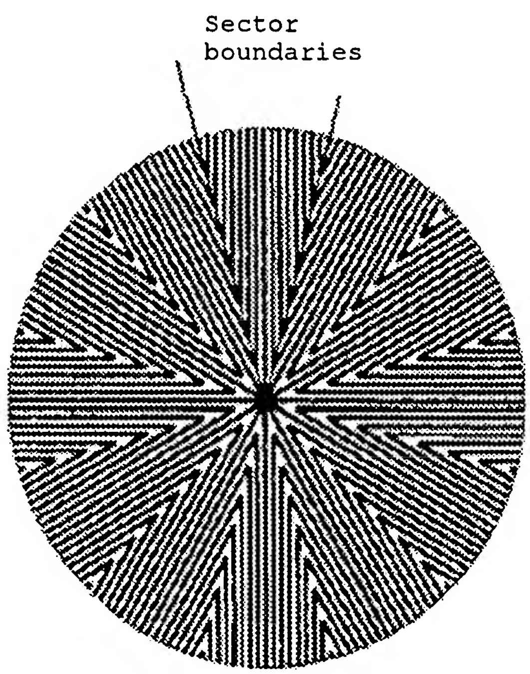

Figure 3

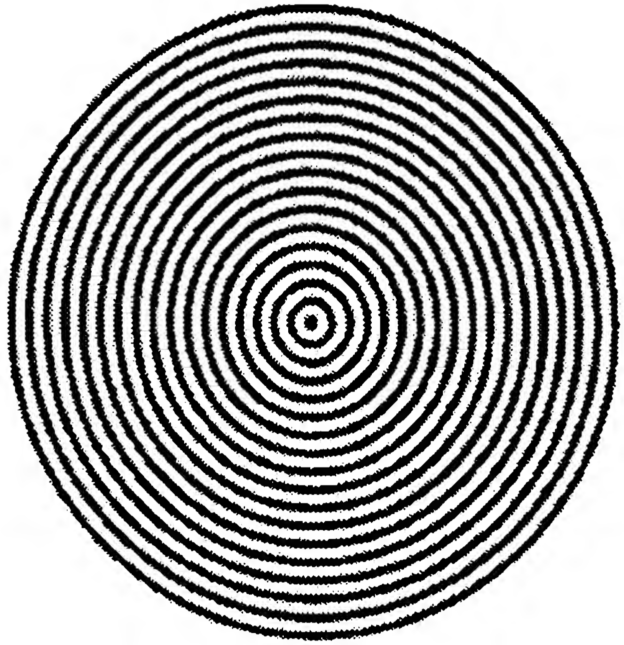

Figure 4